



Remote sensing of aerosols and clouds: Techniques and applications (editorial to special issue in Atmospheric Research)

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ARTICLE INFO

Article history:

Received 18 January 2012

Accepted 13 April 2012

Keywords:

Satellites

Remote sensing

Aerosols

Clouds

ABSTRACT

This editorial to the special issue on “Remote Sensing of Aerosols and Clouds: Techniques and Applications” briefly introduces the subject and its challenges. The history of aerosol and cloud remote sensing is briefly summarized and algorithms are introduced. These issues are further discussed in the contributing articles.

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The retrieval of aerosol and cloud properties from satellite-based observations provides information complementary to ground-based in situ and remote sensing measurements and model simulations of atmospheric composition (cf. Burrows et al., 2011 for an overview of satellite remote sensing of atmospheric composition). Where ground-based measurements provide detailed and relatively accurate information on aerosol and cloud properties applicable to the conditions at the measurement site, satellites provide information on much larger scales from regional to global ranges but with less accuracy and for a limited number of parameters. Instruments on satellite platforms include spectrometers and multi-spectral radiometers, which use wavelengths in the ultra-

violet (UV), visible (VIS), near, mid and thermal infrared (NIR, MIR and TIR) parts of the electro-magnetic spectrum. This limits the observations of particles and droplets in the atmosphere to those with sizes similar to the wavelengths of the radiation with which they interact. For aerosols this corresponds to particles larger than roughly 0.05–0.1 μm ; smaller particles scatter light in the Rayleigh limit, and are therefore undistinguishable from atmospheric gases because the concentrations of the latter are much higher. Hence the number of concentrations of the aerosol particles as observed by satellites is generally not representative of the actual atmospheric concentrations, and thus information on processes dependent on the number of aerosol particles (e.g. activation of cloud condensation nuclei or CCN) is difficult to obtain from satellites. For such situations other techniques are proposed such as the use of proxies (Kulmala et al., 2011). On the other hand, satellite observations do contain information on aerosol mass concentrations, which is important for air quality (e.g. van Donkelaar et al., 2010) and atmospheric chemistry, and on radiative effects on climate which mainly involves solar wavelength in the UV/VIS (Yu et al., 2005; Remer and Kaufman, 2006).

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The challenge to retrieve aerosol properties is to effectively mask any clouds in the instrument's field of view, even the thin sub-visible clouds such as high cirrus, because the high cloud reflectance leads to erroneous aerosol retrievals. Several different techniques have been developed that make optimum use of the instrument properties, especially for instruments which were not designed for this purpose. The second challenge is to separate the effects of the reflectances by the surface and by aerosol particles on the radiation detected at the top of the atmosphere (TOA). This is best achieved over dark surfaces such as the ocean surface in the NIR and dark forest in the VIS. In these cases simple corrections for the surface reflectance often yield good results (Morel and Gentili, 2004; Von Hoyningen-Huene et al., 2003). However, over brighter surfaces the TOA radiation is often overwhelmed by the surface contribution and more sophisticated methods need to be applied such as the application of multiple views (e.g. Flowerdew and Haigh, 1995), polarization or corrections using measurements at different wavelengths. In some cases an appropriate surface reflectance data base can be used.

Once the path radiance due to aerosols only has been determined, the final challenge is to retrieve the aerosol parameters. This is usually done through the application of a radiative transfer model including aerosols. Since radiative modeling is time-consuming and needs to be repeated many times during the retrieval over a scene, the models are run for a representative sample of situations, including sun-satellite geometries, aerosol optical depth (AOD) levels and different aerosol models and the results are stored in look-up tables (LUTs). In the retrieval process the LUT data are interpolated for the actual situation and the AOD is determined from comparison with the path radiance. Ideally this is done for several wavelengths to determine the best aerosol model, or combination of aerosol models, which explains the observations.

Instruments used for satellite remote sensing of aerosols and clouds were often not designed for this purpose. The longest time series of AOD from Earth Observation (EO) instruments has been obtained from the Advanced Very High Resolution Radiometer (AVHRR), which was designed to measure surface temperature and from Total Ozone Mapping Spectrometer (TOMS), which was designed to measure ozone column concentrations. Time series are discussed in, e.g. Zhang and Reid (2010). Several other instruments have been and are being used for the retrieval of aerosol properties, some of which were designed for this purpose. The latter include MODerate Resolution Imaging Spectroradiometer (MODIS), Multi-Angle Imaging Spectroradiometer (MISR), and POLarization and Directionality of the Earth's Reflectances (POLDER). Specific properties are the use of multiple viewing angles and measurements of the degree of polarization of the received light. MODIS has only a single viewing angle but the wavebands used were chosen to optimize the aerosol retrieval. Instruments providing multiple viewing angles are POLDER, MISR and also the Along Track Scanning Radiometer (ATSR) series of instruments of which ATSR-2 and Advanced ATSR (AATSR) are used for aerosol and cloud retrievals. Only POLDER (or the current version PARASOL flying on the A-Train) measures the degree of polarization of reflected solar light. An overview of

properties of current instruments used for aerosol retrieval and their specifications was provided in Kokhanovsky and de Leeuw (2009).

Different aerosol retrieval algorithms have been developed for the different instruments (cf. Kokhanovsky and de Leeuw, 2009; de Leeuw et al., 2011 for an overview) and even for the same instrument different algorithms have been developed which use different instrument properties or which use the instrument properties in different ways. To obtain more information the synergistic use of different instruments flying on the same satellite or in the same constellation is being explored.

The situation in cloud remote sensing is comparable to the aerosol situation in various aspects. Like the retrieval of aerosol properties from a satellite platform, cloud property retrieval presents an inverse problem: radiances registered at the sensor are the data basis upon which the properties of the clouds are inferred. Frequently this is done on the basis of systematic forward radiative transfer modeling, the results of which are then tabulated and used in look-up table approaches (e.g. Kawamoto et al., 2001), whereas other approaches solve a simplified backward model at runtime (cf. Nauss and Kokhanovsky, 2011).

While conventional passive-sensor retrievals of cloud properties, such as droplet effective radius, cloud optical depth and liquid water path become increasingly more sophisticated, two major deficiencies persist: 1) Traditional retrievals are based on the unrealistic assumption of a plane-parallel cloud structure, i.e. the absence of vertical variation within a cloud and homogeneity in the horizontal plane. Much more complex, more advanced approaches have recently been proposed based on theoretical studies (Zinner et al., 2010) and are increasingly being pursued.

2) Climatological evaluation of cloud distribution, cloud properties and changes therein is hampered by discontinuities between satellite systems. The longest available evaluations of cloud properties, by the International Satellite Climatology Project (ISCCP) and Pathfinder Atmospheres extended (PATMOS-x) are based on AVHRR data, plus, in the case of ISCCP, geostationary satellite information. Despite a largely common data basis, the time series look very dissimilar and artifacts have been documented in at least the ISCCP data set (Evan et al., 2007). This means that meaningful analyses of long-term changes in seemingly simple parameters such as total cloud cover are impossible at the moment.

Recent developments in satellite systems have shown promise with respect to the characterization of cloud properties in three dimensions. The use of space-based active sensors such as lidar and radar systems (e.g. CALIOP and CLOUDSat on the A-train constellation of satellites) has allowed for the detailed and accurate retrieval of cloud geometrical and microphysical properties in all dimensions. In combination with passive-sensor data, new insights into cloud property distribution in time and space can be gained.

While problems still exist in aerosol and cloud retrievals, a particular challenge open for future research lies in the understanding of cloud–aerosol interactions. Remote sensing data from ground-based and satellite-based sensors is increasingly being combined with numerical models to tackle this issue of great relevance for climate-system understanding.

Techniques to obtain information on aerosols and cloud from satellite observations and their applications were presented and discussed during the European Geosciences Union General Assembly in Vienna, 3–8 April 2010, for an audience of about 300 scientists. In this special issue a small selection of the work presented during this conference is given.

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